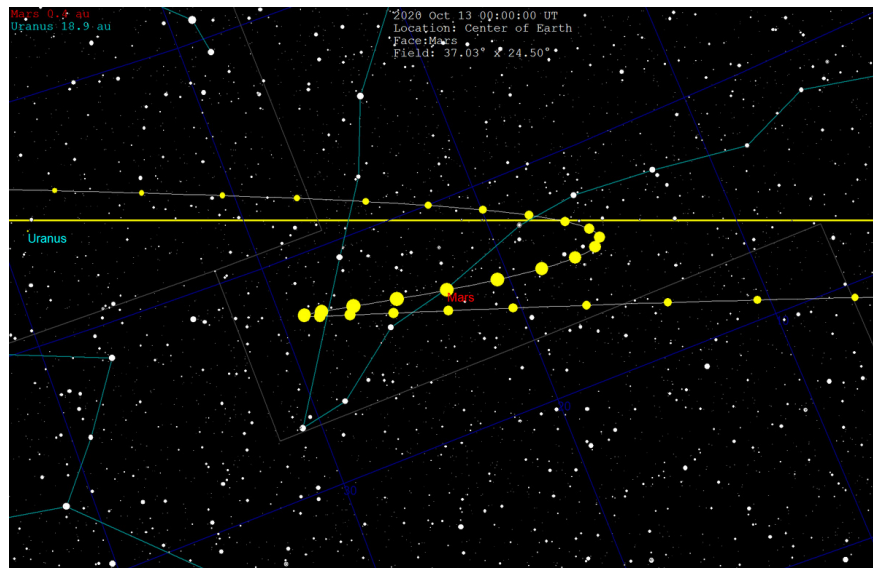


3: The Copernican Revolution

Learning Objectives

- Describe the period leading up to the Copernican Revolution.
- Understand the Copernican Model of a heliocentric universe.
- Describe the contributions of Tycho Brahe and Johannes Kepler.
- Understand Kepler's Laws of Planetary Motion.
- Describe Newton's Laws of Motion and Universal Gravitation.
- Understand Conservation of Energy and Momentum and describe how they explain the motion of planetary bodies.

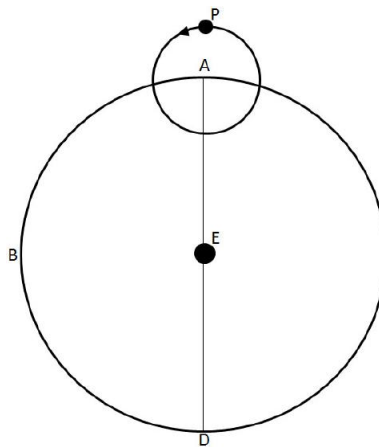
As the Medieval Period gave way to the Renaissance, western scholars began to rediscover the writings of Ptolemy and other ancient Greeks. By this point, errors from Ptolemy's *Almagest* had crept into his calculations and his predictions no longer matched with contemporary observations. Some astronomers even noticed some observations that the Ptolemaic model could not explain, such as the changes in the apparent brightness of Mars throughout the year.



Retrograde Motion of Mars. https://commons.wikimedia.org/wiki/File:Retrograde_motion_2020.png

The five known planets had vexed astronomers for centuries. The Sun, the Moon, and the so-called “fixed stars” all moved in predictable patterns, but the planets did not. They shifted their positions with respect to the fixed stars. They changed in brightness and speed. They engaged in retrograde motion (Chapter 2). Ptolemy published his geocentric model around 140 CE. His model included many **epicycles** to explain retrograde motion. In this model, there are two paths in a planet's orbit around the Earth. The **deferent** goes around the Earth while the epicycle makes a circle around the edge of the deferent. As a result, the planet moves along both the deferent and the epicycle, explaining retrograde motion (figure below).

Ptolemy also included the use of an equant, putting the Earth off center from orbits of the planets. While Ptolemy's model remained the most accurate predictor of planetary motion for centuries, by the 13th centuries, enough errors had crept in that his predictions were off by one or two degrees. This is bigger than the apparent size of the Moon. This discrepancy required more and more complex “corrections” to the Ptolemaic model.



Ptolemy used epicycles to explain retrograde motion of planets like Mars. According to Ptolemy, as a planet's orbit carried it around the Earth, it also made a smaller circle centered on the orbital path.

<https://commons.wikimedia.org/wiki/File:Epicycle-Ptolemy.png>;

Still, Aristotle's advocacy of the geocentric model carried tremendous weight among scholars and religious authorities. Aristotle's words, combined with selected biblical passages that implied that the Sun, not the Earth, moves resulted in geocentrism becoming religious and church dogma throughout most of the Christian world. But there were observational reasons for some to object to heliocentrism. The most significant was the lack of measurable parallax among the stars. If the Earth moved, they asked, why don't the stars shift their positions throughout the year? Also, the heliocentric model proposed by Aristarchus did not make any better predictions than Ptolemy's geocentric model. This was because scholars were unwilling to abandon the assumption that the stars and planets were perfect spheres and moved in perfect circles.



Giordano Bruno was executed by the Catholic Church for his unconventional views on the universe.

https://commons.wikimedia.org/wiki/File:Giordano_Bruno_BW_2.JPG;

The fifteenth through seventeenth centuries were also a time of political and religious upheaval. The Protestant Reformation had begun in earnest and was tearing the Holy Roman Empire (what we call Germany today) apart. The religious authorities could not afford to allow any dissent and clamped down on any perceived heresy as strictly and brutally as possible. For example, an Italian monk named Giordano Bruno proposed that the stars were distant suns that may have planets of their own. For this and other unorthodox beliefs, the Catholic Church had Bruno burned at the stake in 1600. Despite this oppressive atmosphere, the Renaissance was a time for challenging orthodoxy and considering new ideas. The time was ripe for an intellectual revolution. One that would, surprisingly, would be kicked off by a quiet clergyman from Poland.

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